Report Number: PE-09-00

EXPERIMENTAL INSTALLATION OF LARGE DIAMETER (48 in.) HIGH DENSITY POLYETHELENE CULVERT PIPE (HDPE)

CONSTRUCTION REPORT

WISCONSIN
TECHNOLOGY
ADVANCEMENT
DEPARTMENT OF TRANSPORTATION

SEPTEMBER 2000

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
PE-09-00		

4. Title and Subtitle	5. Report Date
Experimental Installation of Large Diameter (48") High Density Polyethylene Culvert Pipe (HDPE)	Sep-00
	6. Performing Organization Code
7. Author(s) Joe Wilson, WisDOT Technology Advancement Specialist	8. Performing Organization Report No.
9. Performing Organization Name and Address Wisconsin Dept. of Transportation Division of Transportation Infrastructure Development Bureau of Highway Construction Pavements Section, Technology Advancement Unit 3502 Kinsman Blvd.. Madison, WI 53704-2507	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Construction Report, Fall of 2000
	14. Sponsoring Agency Code Study # PE 00-04

15. Supplementary Notes

16. Abstract

On August 31st and September 1st, 2000, WisDOT participated in the installation of two different large diameter (48 in.) High Density Polyethylene Culvert Pipes (HDPE) on a low volume county trunk highway in Northwestern Wisconsin in an effort to monitor/test performance issues of these experimental products in a wet, freeze/thaw climate with acidic water conditions. This was a twin pipe installation that replaced a 54 in. corrugated metal culvert pipe that had deteriorated on the bottom due to the acidic water in this particular area. Currently, WisDOT allows up to 36 in. HDPE pipe for culvert installations and was interested in seeing how these large diameter HDPE pipes performed with time and low volume loadings.

The potential benefits of this project include greater versatility in pipe choice to satisfy a variety of environmental conditions, lightweight materials and ease of maneuverability without heavy equipment, and the possibility of reduced installation costs due to additional competition. In addition, longer pipe sections mean fewer joints, reducing the potential for soil infiltration.

Extensive soil testing was performed on this installation, including nuclear density testing of the compacted 12 in. lifts, dynamic cone penetrometer testing, and soil stiffness testing. Deformation measurements were taken initially and will be compared to measurements taken at 7 days, 30 days, 6 months, and 1 year to see if the pipes are holding up to the loadings. In addition, levels were taken of the pipes and will be compared with later measurements to determine how much settlement occurs with time. If the results prove favorable, WisDOT will consider looking at expanding the allowable usage of these large diameter HDPE pipes.

17. Key Words	18. Distribution Statement
HDPE, High Density Polyethylene Pipe, Culvert, compaction, density, dynamic cone penetrometer, performance evaluation	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price

EXPERIMENTAL INSTALLATION OF LARGE DIAMETER (48 in.) HIGH DENSITY POLYETHELENE CULVERT PIPE (HDPE)

Study # PE 00-04

CONSTRUCTION REPORT
Report # PE-09-00

by

Joe Wilson
Wisconsin Department of Transportation
Technology Advancement Specialist

for

WISCONSIN DEPARTMENT OF TRANSPORTATION
DIVISION OF TRANSPORTATION INFRASTRUCTURE DEVELOPMENT
BUREAU OF HIGHWAY CONSTRUCTION
PAVEMENTS SECTION
TECHNOLOGY ADVANCEMENT UNIT
3502 KINSMAN BLVD., MADISON, WI 53704-2507

SEPTEMBER 2000

TABLE OF CONTENTS

PROJECT BACKGROUND

WisDOT is interested in seeing how large diameter (42 in. and 48 in.) High Density Polyethylene Pipe (HDPE) performs in a culvert installation in Wisconsin. Currently WisDOT allows up to 36 in. HDPE pipe for culvert installations where the Average Daily Travel (ADT) is under 4500. A low volume county trunk road with an ADT of 550 vehicles per day was selected for this test installation. If the results prove favorable, WisDOT may consider looking at the possibility of increasing the allowable usage of these materials.

The *objectives* of the study are to look at 1) the cost of the materials, 2) installation, 3) life cycle costs, 4) performance, and 5) construction as compared with standard metal and concrete pipes. Construction issues include the condition of the existing pipe upon removal, installation time, manpower, equipment needed, backfilling/compaction, and alignment/floating during the backfilling. Performance issues include deformation of the pipe at several points in time (initial, 7 days, 30 days, 1 year and later), quality/condition of the joints, resistance to corrosion and abrasion, maintenance (clean out, material build-up, joint leaks, settlement), stress cracks from freeze/thaw, and fluctuation of the pipe flow line. Inspections will be performed initially, 7 and 30 days after construction, 6 months and one year. Inspections will then be carried out yearly after the first year for 4 years.

The *benefits* of this project include greater versatility in pipe choice to satisfy a variety of environmental conditions, lightweight materials, ease of maneuverability without heavy equipment (for smaller diameter pipes), and the possibility of reduced installation costs due to additional competition. In addition, longer pipe sections mean fewer joints reducing the potential for soil infiltration.

The *implementation* of this study is such that the results will determine if WisDOT may consider increasing the maximum allowable size of HDPE pipe as well as increasing the usage on higher volume roads. If the results prove favorable, WisDOT may consider the possibility of updating the Facilities Development Manual (FDM) to reflect any changes WisDOT agrees with upon completion of the spring 2001 inspection.

PROJECT OVERVIEW

The test installation site is located in Northwestern Wisconsin in Polk County on CTH E between State Trunk Highway 48 and County Trunk W. More specifically, CTH E is located in the northeast part of the county, one mile west of the Polk / Barron County Line. This area was chosen in an effort to monitor the performance of the HDPE pipe in a cold, wet freeze/thaw climate with slightly acidic (Ph = 6.3) water and soil conditions. The pipe installation took place as part of a pulverize and relay project of approximately 4.8 miles (Project ID 8850-01-71). All of the culvert pipes used on this project were HDPE pipes.

TESTING PROCEDURES

Soil samples of the bedding and backfill materials (same) were taken to get a measure of the pH of the soil and for proctor densities. Water samples will also be taken to get a pH measure. Ground Penetrating Radar (GPR), Nuclear Density Testing, a Soil Stiffness Gage, and a Dynamic Cone Penetrometer (DCP) were all used to measure various soil condition parameters. These four different types of soil compaction / condition testing were performed in an effort to correlate the various methodologies / instruments, as well as to document the installation's immediate environmental conditions. (A further aim of the extensive soil testing is to determine if WisDOT can come up with some sort of Quality Control / Quality Assurance (QC/QA) program or some kind of density requirement / specification for pipe installations due to limited field personnel for inspections of all aspects of construction management.

The pipes were also measured for deformation. Initial measurements were taken at marked points inside the pipe at 9 and 3 o'clock, 12 and 6 o'clock and at the two midpoints of these points. These pipe diameter measurements were taken at either end and repeated at approximately ten-foot increments throughout the length of the pipes including the joints and midpoints of each pipe section. See deformation tables starting on page 20.

Settlement of the pipes will be monitored as well. Elevations were shot on each of the pipes at the inlets and outlets. These initial readings will be compared with follow-up elevations to determine, if any, settlement occurs with time. It is anticipated that some settlement will occur within 30 days after installation. Thus, the final report will include an analysis of any settlement that occurred.

PIPE INSTALLATION

For this installation, two different HDPE pipes were laid side by side as a twin pipe installation (see photos at the end of this report). Approximately 4'-5' of fill or cover was placed over the pipes. Both pipes were a nominal 48 in. diameter; the more southern pipe was manufactured by ADS and had a smooth exterior, while the pipe placed on the north side was manufactured by Hancor and had a corrugated / ribbed exterior. Both pipes were relatively smooth on the interior. The Manning's coefficient of friction for the ADS pipe is 0.12, while the Manning's "n" for the Hancor pipe is 0.10. The Manning's "n" is a term used to describe a material's roughness. For comparison, a typical Manning's coefficient for concrete pipe ranges from 0.011-0.015, while corrugated metal pipe with ½ in. x 2 ½ in. corrugations ranges from 0.022-0.026. The same reference source (Jennings et al., 1994) shows smooth plastic pipe as having a Manning's coefficient ranging from 0.011-0.015. Installation of the new HDPE pipes took place on August 31st and September 1st, 2000. Alliance Construction of Superior, Wisconsin was the contractor.

Upon removal of the existing 54 in. corrugated metal pipe (Prints 1-7, Appendix C), it was observed that the bottom of the pipe was deteriorated and corroded, probably due to standing acidic water in the bottom of the pipe. It was estimated that the pipe was approximately 25 years old.

It was learned that a recent 12 in. rainfall in the area had flooded the roadway and water was flowing over the road. The storm had lodged a large tree trunk approximately 10 feet long and 18 in. in diameter at the old pipe inlet indicating significant flow during storm events.

A concern of the ADS pipe related to its construction: this pipe needs to be ordered in exact lengths as it cannot be cut in the field due to the nature of its construction. A cross-section of the pipe has hollow “channels” that could allow water to flow through the shell of the pipe itself. In addition, the end of the pipe does not have corrugations to attach the end wall aprons securely. This may result in rotation of the apron endwalls. As previously mentioned, the ADS pipe was not corrugated on the outside. It is unknown whether or not this will present a stability problem with large flows, i.e. will the pipe stay in place without the corrugated exterior helping to “hold” the pipe in place due to increased friction.

After removal of the existing pipe, the bed was prepared with an 18 in. lift of sand and compacted prior to placement of the pipe sections. Five lifts were then added and compacted in 12 in. increments to bring the backfill material up to and over the top of the pipes, at which point 3 more lifts of approximately 18 in. were placed and compacted to bring the subgrade up to the level of the roadway. All bedding and backfill material was sand.

It took approximately 16 hours total time for the installation including removing the existing pipe and installing the new pipes and backfilling back up to the level of the roadway. It is noted that both company representatives were quite pleased with the backfill and compaction effort that was put forth in this installation, they hadn’t observed any other installations of their products that had as much effort put forth into the backfilling and compaction operation. In addition, the construction workers reported no problems with pipe floating / alignment during installation and joining pipe sections.

NUCLEAR DENSITY TESTING

Nuclear density testing was performed at nine different locations as shown in Figure 1 in Appendix A. Tests were conducted at the nine sites for the bedding and then repeated at approximately the same location for each successive lift. A Troxler 3440 nuclear density machine was used for the density tests. The test method was ASTM D2922. The tests were performed by Cooper Engineering Inc.. The results show that the average relative compaction for 51 total tests was 101.7 percent. Table 1 on the following page contains the complete Nuclear Density Data.

Test Number	Approx. Elevation	Dry Density (pcf)	Moisture (percent)	Wet Density (pcf)	Maximum Density (pcf)	Proctor Sample Number	Relative Compaction (percent)
1a	Pipe Bed	114.0	5.7	120.4	110.9	P-1	102.8
2a	Pipe Bed	113.2	9.4	123.9	110.9	P-1	102.1
3a	Pipe Bed	117.3	5.6	123.8	110.9	P-1	105.7
4a	Pipe Bed	123.6	4.9	129.6	110.9	P-1	111.4
5a	Pipe Bed	115.7	8.0	125.0	110.9	P-1	104.4
6a	Pipe Bed	119.0	5.1	125.1	110.9	P-1	107.3
7a	Pipe Bed	125.0	5.2	131.5	110.9	P-1	112.7
8a	Pipe Bed	116.8	6.4	124.2	110.9	P-1	105.3
9a	Pipe Bed	114.0	12.5	128.3	110.9	P-1	102.8
1b	1' lift	111.3	7.2	119.3	110.9	P-1	100.4
2b	1' lift	112.5	6.0	119.2	110.9	P-1	101.4
3b	1' lift	113.8	5.9	120.5	110.9	P-1	102.6
4b	1' lift	113.7	6.2	120.8	110.9	P-1	102.6
5b	1' lift	110.8	7.4	119.0	110.9	P-1	99.9
6b	1' lift	109.8	5.6	115.9	110.9	P-1	99.0
7b	1' lift	116.8	8.7	127.0	110.9	P-1	105.3
8b	1' lift	112.6	9.4	123.1	110.9	P-1	101.5
9b	1' lift	111.9	6.6	119.3	110.9	P-1	100.9
1c	2' lift	114.2	5.1	120.0	110.9	P-1	103.0
2c	2' lift	112.6	6.1	119.5	110.9	P-1	101.5
3c	2' lift	113.7	5.4	119.9	110.9	P-1	102.5
4c	2' lift	110.9	8.4	120.3	110.9	P-1	100.0
5c	2' lift	107.6	6.9	115.1	110.9	P-1	97.1
6c	2' lift	110.9	5.9	117.4	110.9	P-1	100.0
7c	2' lift	112.4	5.0	118.1	110.9	P-1	101.4
8c	2' lift	113.4	7.2	121.6	110.9	P-1	102.3
9c	2' lift	110.4	6.3	117.4	110.9	P-1	99.6
1d	3' lift	115.6	4.6	120.9	110.9	P-1	104.2
2d	3' lift	112.7	5.8	119.2	110.9	P-1	101.6
3d	3' lift	112.6	5.7	118.9	110.9	P-1	101.5
4d	3' lift	108.7	5.6	114.8	110.9	P-1	98.0
5d	3' lift	108.0	5.5	113.9	110.9	P-1	97.4
6d	3' lift	107.8	6.8	115.1	110.9	P-1	97.2
7d	3' lift	111.4	5.6	117.7	110.9	P-1	100.5
8d	3' lift	112.5	5.5	118.7	110.9	P-1	101.4
9d	3' lift	111.3	5.5	117.4	110.9	P-1	100.4
1e	4' lift	113.3	5.4	119.4	110.9	P-1	102.2
2e	4' lift	112.2	6.3	119.2	110.9	P-1	101.2
3e	4' lift	110.6	6.0	117.2	110.9	P-1	99.8
4e	4' lift	106.8	5.8	112.9	110.9	P-1	96.3
5e	4' lift	110.2	9.0	120.0	110.9	P-1	99.3
6e	4' lift	113.3	5.5	119.5	110.9	P-1	102.2
7e	4' lift	106.7	5.0	112.0	110.9	P-1	96.2
8e	4' lift	107.9	5.3	113.6	110.9	P-1	97.3
9e	4' lift	108.5	7.7	117.0	110.9	P-1	97.9
10f*	5 1/2' lift	112.6	3.7	112.6	110.9	P-1	97.9
11f**	5 1/2' lift	119.4	5.5	125.9	110.9	P-1	107.6
10g*	7' lift	112.0	7.0	119.8	110.9	P-1	101.0
11g**	7' lift	114.7	4.6	120.0	110.9	P-1	103.4
10h*	8' lift	115.2	5.4	121.5	110.9	P-1	103.9
11h**	8' lift	115.2	6.1	122.3	110.9	P-1	103.9

* Readings taken between the pipes in the North Bound Lane. **AVE = 101.7**

** Readings taken between the pipes in the South Bound Lane.

DYNAMIC CONE PENETROMETER TESTING

Dynamic Cone Penetrometer (DCP) Testing was performed at the same locations and layout as was done with the nuclear density testing. This was done in order to collect California Bearing Ratio (CBR) data and be able to directly correlate this data to the nuclear density testing done in the same locations. Appendix B contains some information and a chart that correlates DCP data with work that was done by the Corps of Engineers and the Illinois Department of Transportation to arrive at a CBR value for the DCP data. Initial intentions for performing the DCP testing were to test each lift and continue the testing to the bottom of the bedding material / layer. This was modified in the field such that each test site was tested to an approximate depth of 45 inches (length of the DCP rod). This was done to expedite construction (as well as for equipment and practicality limitations) and thus is noted so as to take into account for any correlation analyses. It is anticipated that the final report for this project will include an analysis of the data. See Table 2 in Appendix A for the complete test results.

GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) was used on this project after completion of the installation in an attempt to gather as much data as possible and to make possible future correlations with the other soil testing procedures. It is anticipated that the final report will include an analysis of the results of this testing.

SOIL STIFFNESS TESTING

Soil stiffness testing was performed for the trench bed and for the final lift. The results of this testing are on the following page. It is anticipated that the final report for this project will include an analysis of the data.

Table 3

Soil Stiffness Results (from GeoGauge)

Layer a (Pipe Bed) Possion's Ratio 0.35

Test No.	Stiffness (MN/m)	Moisture Content (% by weight/100)		Dry Density (pcf)		Young's Modulus (MPa)
		Nuclear Gauge [1]	Laboratory [2]	[1]	[2]	
1	6.29962	0.057	0.062	114.04	113.17	54.65
2	6.40971	0.094	0.062	108.42	113.36	55.60
4	6.72297	0.049	0.062	116.08	113.85	58.32
5	5.71364	0.08	0.062	109.02	112.11	49.56
7	7.27435	0.052	0.062	116.25	114.64	63.10
8	6.51131	0.064	0.062	113.19	113.52	56.48

Layer e (4th Lift)

Test No.	Stiffness (MN/m)	Moisture Content (% by weight/100)		Dry Density (pcf)		Young's Modulus (MPa)
		Nuclear Gauge [1]	Laboratory [2]	[1]	[2]	
1	5.69039	0.054	0.062	113.5571	112.0613	49.36
4	5.99289	0.058	0.062	113.3518	112.6367	51.99
7	4.75191	0.05	0.062	112.4507	109.9211	41.22

PIPE DEFORMATION MEASUREMENTS

Measurements were taken for both pipes to monitor deformation. Deformation measurements were taken at eleven (11) sites along the length of each pipe and were marked with paint so that future measurements would be consistently taken at the same points. Basically, the measurements were taken at the end- and mid-points of each pipe section. The measurements were taken on four different axes: from twelve o'clock to six o'clock, from nine o'clock to three o'clock, and the two 45° midpoints of these sectors. Measurements were taken immediately after installation, then at one week and then at one month. These tables are in appendix A beginning on page 20.

FLOWLINE PROFILE

Elevations were shot at each inlet and outlet of both pipes after installation and will be combined with flowline measurements (which will be converted to elevations) taken inside the pipes to monitor any settlement that may occur with time. Initial measurements can be found in the table on page 25.

RESULTS / CONCLUSIONS / OBSERVATIONS

1. Installation of the new pipes was straightforward. There were no problems and the pipes were not damaged during installation. A crew of five workers installed the pipe along with a bucket operator, a gas powered hand drawn compactor, a vibratory steel wheel roller operator and a bulldozer operator.
2. Alliance Construction workers reported no problems with the joints when joining pipe sections.
3. Compaction effort was higher than "normal", i.e. greater care and effort was exercised in ensuring adequate compaction.
4. Some concern exists for attachment of the end wall apron on the ADS pipe as there is no bell housing or flange to securely attach the end wall apron.

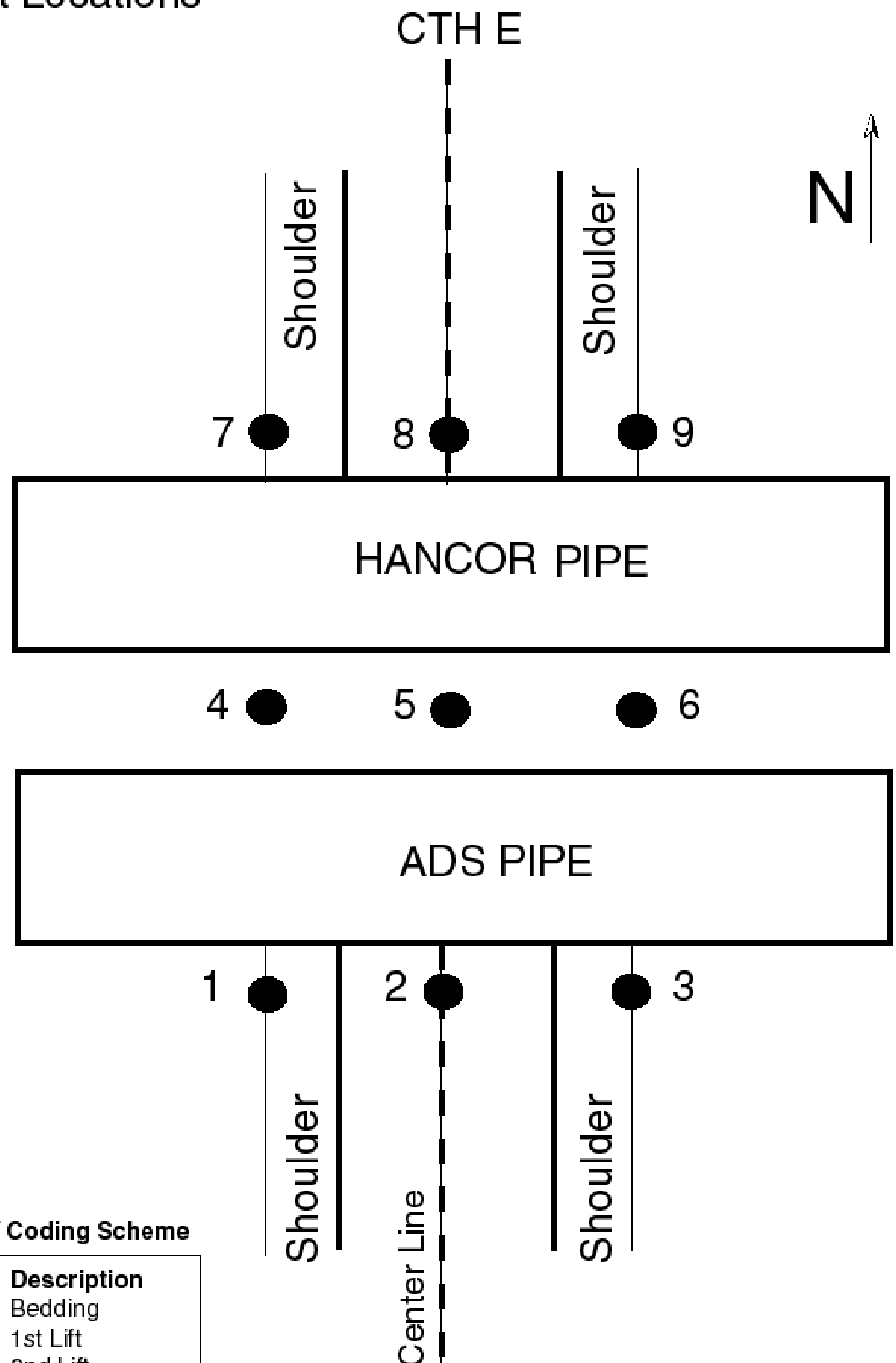
RECOMMENDATIONS

1. Continue to monitor and inspect the pipe at 6 months, 1 year and yearly after that for 4 years for additional deformation, settlement (flow line profile), stress cracks and overall performance.
2. Include an analysis of the soil stiffness testing with the Geogauge for the final report.
3. Include an analysis of the dynamic cone penetrometer testing for the final report.
4. Include an analysis of the ground penetrating radar testing for the final report.

APPENDIX A

FIGURE 1

Soil Test Locations



Soil Testing / Coding Scheme

Test Site	Description
1a	Bedding
1b	1st Lift
1c	2nd Lift
1d	3rd Lift
etc.	etc.

"NOT TO SCALE"

Table 2 Dynamic Cone Penetrometer Test Results

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
1a	1	0	6.4			
1a	2	1	11.0	4.6	4.60	< 1
1a	3	3	18.6	7.6	2.53	2.5
1a	4	3	23.2	4.6	1.53	4
1a	5	5	24.4	1.2	0.24	> 9
2a	1	0	7.0			
2a	2	2	17.0	10.0	5.00	< 1
2a	3	5	24.2	7.2	1.44	4.4
2a	4	5	27.8	3.6	0.72	> 9
2a	5	6	31.8	4.0	0.67	> 9
3a	1	0	5.6			
3a	2	3	16.8	11.2	3.73	1.4
3a	3	4	27.3	10.5	2.63	2.1
3a	4	3	43.8	16.5	5.50	< 1
3a	5	2	45.8	2.0	1.00	7
4a	1	0	5.2			
4a	2	2	10.2	5.0	2.50	2.2
4a	3	3	15.4	5.2	1.73	3.2
4a	4	5	23.2	7.8	1.56	3.9
4a	5	3	24.2	1.0	0.33	> 9
5a	1	0	6.2			
5a	2	4	15.4	9.2	2.30	2.5
5a	3	5	20.8	5.4	1.08	6.2
5a	4	4	24.4	3.6	0.90	8
5a	5	4	26.0	1.6	0.40	> 9
5a	6	5	31.4	5.4	1.08	6.2
5a	7	3	32.0	0.6	0.20	> 9
7a	1	0	5.0			
7a	2	3	10.2	5.2	1.73	3.2
7a	3	4	17.2	7.0	1.75	3.3
7a	4	6	27.8	10.6	1.77	3.4
7a	5	4	32.6	4.8	1.20	5.5
8a	1	0	6.0			
8a	2	2	15.4	9.4	4.70	< 1
8a	3	2	21.2	5.8	2.90	1.9
8a	4	5	25.4	4.2	0.84	8.6
9a	1	0	5.8			
9a	2	6	21.7	15.9	2.65	2.2
9a	3	1	22.0	0.3	0.30	> 9
9a	4	3	36.4	14.4	4.80	< 1
9a	5	5	38.8	2.4	0.48	> 9
9a	6	5	41.3	2.5	0.50	> 9
9a	7	4	43.0	1.7	0.43	> 9
9a	8	5	45.5	2.5	0.50	> 9

Table 2 Dynamic Cone Penetrometer Test Results (Continued)

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
1b	1	0	6.0			
1b	2	5	17.4	11.4	2.28	2.6
1b	3	5	23.4	6.0	1.20	5.5
1b	4	5	28.5	5.1	1.02	7
1b	5	5	31.2	2.7	0.54	> 9
2b	1	0	6.2			
2b	2	5	17.2	11.0	2.20	2.7
2b	3	5	25.5	8.3	1.66	3.5
2b	4	5	26.0	0.5	0.10	> 9
2b	5	5	26.8	0.8	0.16	> 9
3b	1	0	5.8			
3b	2	7	18.5	12.7	1.81	3.3
3b	3	3	25.0	6.5	2.17	2.7
3b	4	4	30.0	5.0	1.25	5.4
3b	5	4	31.3	1.3	0.33	> 9
3b	6	4	32.8	1.5	0.37	> 9
3b	7	5	35.9	3.1	0.62	> 9
3b	8	5	37.4	1.5	0.30	> 9
3b	9	5	39.5	2.1	0.42	> 9
3b	10	5	41.0	1.5	0.30	> 9
3b	11	5	43.0	2.0	0.40	> 9
4b	1	0	6.0			
4b	2	4	18.6	12.6	3.15	1.8
4b	3	5	23.2	4.6	0.92	8
4b	4	5	26.4	3.2	0.64	> 9
4b	5	5	30.0	3.6	0.72	> 9
4b	6	5	35.8	5.8	1.16	5.6
4b	7	3	40.7	4.9	1.63	3.7
4b	8	5	42.0	1.3	0.26	> 9
5b	1	0	6.4			
5b	2	3	20.4	14.0	4.67	< 1
5b	3	3	24.0	3.6	1.20	5.5
5b	4	5	30.0	6.0	1.20	5.5
5b	5	5	31.7	1.7	0.34	> 9
6b	1	0	6.4			
6b	2	5	15.4	9.0	1.80	3.3
6b	3	5	20.7	5.3	1.06	6.4
6b	4	5	27.0	6.3	1.26	5.4
6b	5	4	33.4	6.4	1.60	3.7
6b	6	5	35.7	2.3	0.46	> 9
6b	7	5	37.7	2.0	0.40	> 9
6b	8	5	39.7	2.0	0.40	> 9
6b	9	5	41.8	2.1	0.42	> 9

Table 2 Dynamic Cone Penetrometer Test Results (Continued)

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
7b	1	0	6.4			
7b	2	1	10.6	4.2	4.20	1.1
7b	3	3	17.2	6.6	2.20	2.6
7b	4	4	26.6	9.4	2.35	2.5
7b	5	4	33.8	7.2	1.80	3.3
7b	6	4	42.0	8.2	2.05	2.9
7b	7	4	45.0	3.0	0.75	> 9
8b	1	0	7.0			
8b	2	3	14.2	7.2	2.40	2.3
8b	3	4	19.8	5.6	1.40	4.5
8b	4	5	25.2	5.4	1.08	6.2
8b	5	5	27.6	2.4	0.48	> 9
8b	6	5	29.0	1.4	0.28	> 9
9b	1	0	6.6			
9b	2	4	23.6	17.0	4.25	1.1
9b	3	5	30.4	6.8	1.36	4.7
9b	4	5	34.4	4.0	0.80	9
9b	5	5	40.7	6.3	1.26	5.4
9b	6	5	44.4	3.7	0.74	> 9
9b	7	2	45.0	0.6	0.30	> 9
1c	1	0	5.8			
1c	2	5	18.0	12.2	2.44	2.4
1c	3	5	28.2	10.2	2.04	2.9
1c	4	4	42.6	14.4	3.60	1.6
1c	5	1	46.0	3.4	3.40	1.4
2c	1	0	5.4			
2c	2	3	13.9	8.5	2.83	1.9
2c	3	4	20.8	6.9	1.73	3.5
2c	4	5	26.6	5.8	1.16	5.6
2c	5	5	34.7	8.1	1.62	3.6
2c	6	3	41.4	6.7	2.23	2.7
2c	7	3	42.2	0.8	0.27	> 9
3c	1	0	5.8			
3c	2	5	14.8	9.0	1.80	3.3
3c	3	5	18.7	3.9	0.78	> 9
3c	4	5	22.7	4.0	0.80	9
3c	5	5	27.4	4.7	0.94	7.6
3c	6	4	33.2	5.8	1.45	4.4
3c	7	4	38.2	5.0	1.25	5.7
3c	8	4	40.0	1.8	0.45	> 9
3c	9	4	43.6	3.6	0.90	8
3c	10	5	46.0	2.4	0.48	> 9

Table 2 Dynamic Cone Penetrometer Test Results (Continued)

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
4c	1	0	5.2			
4c	2	5	22.2	17.0	3.40	1.4
4c	3	5	28.8	6.6	1.32	4.9
4c	4	6	36.1	7.3	1.22	5.4
4c	5	5	39.1	3.0	0.60	> 9
4c	6	5	41.7	2.6	0.52	> 9
5c	1	0	6.4			
5c	2	4	17.8	11.4	2.85	1.9
5c	3	4	28.2	10.4	2.60	2.1
5c	4	5	35.0	6.8	1.36	4.6
5c	5	5	36.6	1.6	0.32	> 9
6c	1	0	6.0			
6c	2	5	15.3	9.3	1.86	3.1
6c	3	5	22.0	6.7	1.34	4.8
6c	4	5	25.6	3.6	0.72	> 9
6c	5	4	28.2	2.6	0.65	> 9
6c	6	5	31.9	3.7	0.74	> 9
6c	7	5	37.1	5.2	1.04	6.6
6c	8	5	43.8	6.7	1.34	4.8
6c	9	4	46.0	2.2	0.55	> 9
7c	1	0	5.8			
7c	2	2	11.2	5.4	2.70	2
7c	3	4	17.1	5.9	1.48	4.1
7c	4	5	26.5	9.4	1.88	3.1
7c	5	4	37.6	11.1	2.78	1.9
7c	6	4	44.6	7.0	1.75	3.4
8c	1	0	6.0			
8c	2	4	14.0	8.0	2.00	2.9
8c	3	3	17.0	3.0	1.00	7
8c	4	4	20.2	3.2	0.80	9
8c	5	4	23.1	2.9	0.73	> 9
8c	6	5	27.4	4.3	0.86	8.4
8c	7	5	30.8	3.4	0.68	> 9
8c	8	5	31.9	1.1	0.22	> 9
9c	1	0	6.0			
9c	2	6	18.8	12.8	2.13	2.8
9c	3	5	27.3	8.5	1.70	3.5
9c	4	4	35.9	8.6	2.15	2.8
9c	5	5	40.2	4.3	0.86	8.4
9c	6	4	45.7	5.5	1.38	4.6

Table 2 Dynamic Cone Penetrometer Test Results (Continued)

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
1d	1	0	6.1			
1d	2	3	14.5	8.4	2.80	1.9
1d	3	5	21.0	6.5	1.30	5
1d	4	5	26.4	5.4	1.08	6.2
1d	5	5	32.1	5.7	1.14	5.8
1d	6	5	36.5	4.4	0.88	8.2
1d	7	5	41.6	5.1	1.02	6.8
1d	8	3	45.2	3.6	1.20	5.5
2d	1	0	6.4			
2d	2	4	15.8	9.4	2.35	2.4
2d	3	4	20.6	4.8	1.20	5.5
2d	4	4	27.0	6.4	1.60	3.7
2d	5	4	32.2	5.2	1.30	5
2d	6	4	36.6	4.4	1.10	6
2d	7	4	40.0	3.4	0.85	8.5
2d	8	4	44.5	4.5	1.13	5.8
2d	9	1	46.0	1.5	1.50	4
3d	1	0	6.2			
3d	2	5	15.6	9.4	1.88	3.1
3d	3	5	20.0	4.4	0.88	8.2
3d	4	5	23.4	3.4	0.68	> 9
3d	5	5	26.3	2.9	0.58	> 9
3d	6	5	29.2	2.9	0.58	> 9
3d	7	5	32.9	3.7	0.74	> 9
3d	8	5	37.2	4.3	0.86	8.4
3d	9	5	41.5	4.3	0.86	8.4
3d	10	3	46.5	5.0	1.67	3.6
4d	1	0	6.4			
4d	2	5	18.4	12.0	2.40	2.3
4d	3	5	30.0	11.6	2.32	2.4
4d	4	5	34.7	4.7	0.94	7.6
4d	5	5	41.6	6.9	1.38	4.6
4d	6	2	44.5	2.9	1.45	4.4
4d	7	2	45.7	1.2	0.60	> 9
5d	1	0	6.6			
5d	2	2	14.2	7.6	3.80	1.3
5d	3	3	18.0	3.8	1.27	5.3
5d	4	3	22.2	4.2	1.40	4.5
5d	5	4	27.1	4.9	1.23	5.4
5d	6	4	36.8	9.7	2.43	2.3
5d	7	4	41.1	4.3	1.08	6.2
5d	8	4	45.4	4.3	1.08	6.2

Table 2 Dynamic Cone Penetrometer Test Results (Continued)

Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
6d	1	0	7.0			
6d	2	4	18.4	11.4	2.85	1.9
6d	3	5	24.0	5.6	1.12	5.9
6d	4	4	29.3	5.3	1.33	4.9
6d	5	5	34.5	5.2	1.04	6.6
6d	6	5	38.6	4.1	0.82	8.8
6d	7	4	42.4	3.8	0.95	7.5
6d	8	4	47.0	4.6	1.15	5.7
7d	1	0	6.6			
7d	2	5	17.0	10.4	2.08	2.7
7d	3	5	23.7	6.7	1.34	4.6
7d	4	5	36.4	12.7	2.54	2.2
7d	5	3	45.0	8.6	2.87	1.9
7d	6	1	47.0	2.0	2.00	2.9
8d	1	0	6.0			
8d	2	5	15.9	9.9	1.98	2.9
8d	3	5	19.7	3.8	0.76	> 9
8d	4	5	23.7	4.0	0.80	9
8d	5	5	27.0	3.3	0.66	> 9
8d	6	5	30.0	3.0	0.60	> 9
8d	7	5	33.1	3.1	0.62	> 9
8d	8	5	36.0	2.9	0.58	> 9
8d	9	5	38.4	2.4	0.48	> 9
8d	10	5	42.9	4.5	0.90	8
8d	11	5	45.3	2.4	0.48	> 9
9d	1	0	9.8			
9d	2	5	17.2	7.4	1.48	4.1
9d	3	5	26.7	9.5	1.90	3
9d	4	5	33.0	6.3	1.26	5.2
9d	5	5	39.0	6.0	1.20	5.5
9d	6	4	45.9	6.9	1.73	3.5
1e	1	0	6.0			
1e	2	3	18.2	12.2	4.07	1.1
1e	3	5	23.7	5.5	1.10	6
1e	4	4	28.4	4.7	1.18	5.6
1e	5	1	29.3	0.9	0.90	8
1e	6	3	32.0	2.7	0.90	8
1e	7	4	34.7	2.7	0.68	> 9
1e	8	6	39.0	4.3	0.72	> 9
1e	9	5	43.4	4.4	0.88	8.2
1e	10	2	45.5	2.1	1.05	6.5

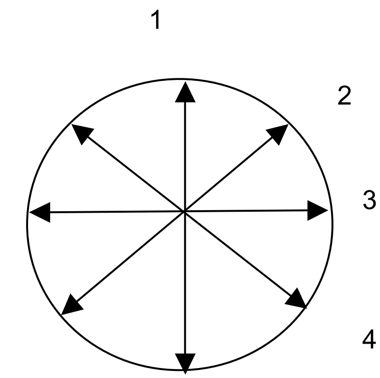
Table 2 Dynamic Cone Penetrometer Test Results (Continued)

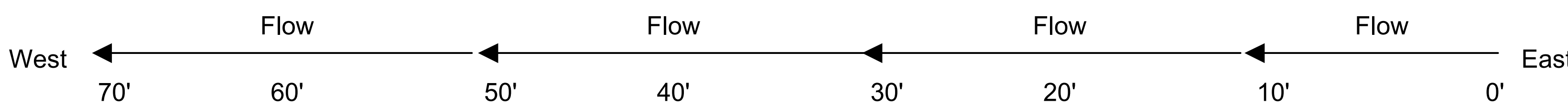
Dynamic Cone Penetrometer (DCP) Testing

Site	Reading Number	Number of Drops	Scale Reading (inches)	Accumulated Penetration (inches)	Penetration per Drop (inches/drop)	Approx. CBR
9e	1	0	5.8			
9e	2	5	26.2	20.4	4.08	1.1
9e	3	5	32.4	6.2	1.24	5.3
9e	4	5	39.0	6.6	1.32	4.9
9e	5	3	45.8	6.8	2.27	2.6
2f	1	0	6.8			
2f	2	5	17.0	10.2	2.04	2.9
2f	3	5	28.0	11.0	2.20	2.7
2f	4	5	34.8	6.8	1.36	4.6
2f	5	5	41.1	6.3	1.26	5.4
2f	6	3	45.1	4.0	1.33	4.9
3f	1	0	6.6			
3f	2	5	17.5	10.9	2.18	2.8
3f	3	5	29.2	11.7	2.34	2.5
3f	4	5	38.0	8.8	1.76	3.4
3f	5	5	45.8	7.8	1.56	3.9
5f	1	0	6.4			
5f	2	5	17.2	10.8	2.16	2.9
5f	3	5	21.2	4.0	0.80	9
5f	4	5	24.0	2.8	0.56	> 9
5f	5	5	27.4	3.4	0.68	> 9
5f	6	5	31.5	4.1	0.82	8.8
5f	7	5	37.0	5.5	1.10	6
5f	8	5	41.4	4.4	0.88	8.2
5f	9	5	45.4	4.0	0.80	9
6f	1	0	6.5			
6f	2	5	15.0	8.5	1.70	3.5
6f	3	5	19.2	4.2	0.84	8.6
6f	4	5	22.5	3.3	0.66	> 9
6f	5	5	26.6	4.1	0.82	8.8
6f	6	5	30.5	3.9	0.78	> 9
6f	7	5	33.7	3.2	0.64	> 9
6f	8	5	37.8	4.1	0.82	8.8
6f	9	5	42.3	4.5	0.90	8
6f	10	6	45.7	3.4	0.57	> 9

Pipe Deformation Measurements
September 1, 2000

CTH E, Polk County
2 Miles north of McKinley, WI.
Measurements by Ken Lewis (ADS)





	Spigot	Hancor - 1	Bell	Spigot	Hancor - 2	Bell	Spigot	Hancor - 3	Bell	Spigot	Bell
1)	48 3/16	48 7/8	48 7/8	48 5/8	48 1/2	48 9/16	48 1/2	48 11/16	48 1/2	48 3/16	48 1/4
2)	47 5/8	48 3/4	48 1/4	47 7/8	48 1/16	47 3/4	47 7/8	48 5/8	48 1/16	47 5/8	47 13/16
3)	47 15/16	47 3/4	47 5/8	47 1/4	48	47 5/8	47 3/8	47 15/16	48 1/4	47 1/2	48 11/16
4)	48 3/8	48 1/4	48 1/4	48 1/16	48 3/8	48 5/8	48 1/16	48 1/4	49 1/16	48 1/2	48 5/8

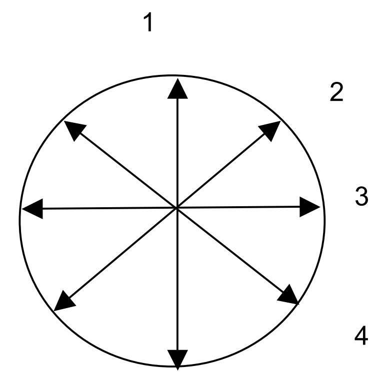
	Spigot	ADS - 1	Bell	Spigot	ADS - 2	Bell	Spigot	ADS - 3	Bell	Spigot	Bell
1)	47	47 5/8	47 3/8	47 1/8	47 3/4	47 3/16	47 1/8	47 3/4	47 7/8	47 7/8	46 3/4
2)	47 1/4	47	47	46 15/16	46 7/8	46 13/16	47 1/8	46 13/16	46 1/2	46 7/8	46 3/4
3)	47 3/16	46 5/8	46 1/2	46 7/16	46	46 1/16	46 5/8	46 3/8	45 13/16	46 3/16	47 1/16
4)	46 3/4	47 1/8	46 3/4	46 3/4	46 1/2	46 5/8	46 7/8	46 7/8	46 7/8	47 1/16	46 7/8

Notes:

A) All measurements facing West
B) All measurements in inches
C) 48" Hancor and ADS HDPE pipe with 3-4 feet of cover
D) Trench subcut to 1 1/2 feet below bottom of pipe
E) Backfill material - graded sand and compacted to 95% proctor density

Pipe Deformation Measurements
September 8, 2000

CTH E, Polk County
2 Miles north of McKinley, WI.
Measurements by Kevin Yale (ADS) & Roger Baldwin (Hancor)



Flow — Flow — Flow — Flow

West ← → East

70' 60' 50' 40' 30' 20' 10' 0'

	Spigot	Hancor - 1	Bell	Spigot	Hancor - 2	Bell	Spigot	Hancor - 3	Bell	Spigot	Bell
1)	48 5/8	48 5/8	48 5/8	48 5/8	48 7/16	48 1/2	48 3/8	48 1/2	48 1/2	48 1/4	48 11/16
2)	47 7/8	48 9/16	47 9/16	47 1/2	47 3/4	47 9/16	47 3/4	48 3/8	47 13/16	47 1/2	48 1/4
3)	46 7/8	47 11/16	47	46 15/16	48	47 7/16	47 1/4	47 7/8	47 7/8	47 3/8	48 1/8
4)	48 5/8	47 15/16	48 3/8	48 1/4	48 1/4	48 5/8	48 1/8	48 1/4	48 3/4	48 11/16	48

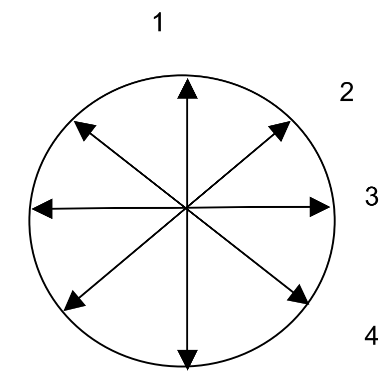
	Spigot	ADS - 1	Bell	Spigot	ADS - 2	Bell	Spigot	ADS - 3	Bell	Spigot	Bell
1)	47 5/8	47 1/2	47 3/8	47 3/16	47 3/4	47 1/16	46 15/16	47 3/4	47 7/8	47 15/16	47 3/8
2)	47 1/4	46 7/8	46 3/4	46 5/8	46 7/8	46 7/8	47 1/8	46 3/4	46 11/16	47	46 7/8
3)	46 1/4	46 9/16	46 1/4	46 3/16	45 7/8	46	46 5/8	46 1/4	45 15/16	46 1/4	46 1/4
4)	46 11/16	48	46 15/16	46 7/8	46 1/4	46 5/8	46 3/4	46 3/4	46 1/2	46 13/16	46 1/2

Notes:

A) All measurements facing West
B) All measurements in inches
C) 48" Hancor and ADS HDPE pipe with 3-4 feet of cover
D) Trench subcut to 1 1/2 feet below bottom of pipe
E) Backfill material - graded sand and compacted to 95% proctor density

Pipe Deformation Measurements
October 4, 2000

CTH E, Polk County
2 Miles north of McKinley, WI.
Measurements by Robert Reukema (WisDOT) & Roger Baldwin (Hancor)



West ← Flow ← Flow ← Flow ← Flow East

70' 60' 50' 40' 30' 20' 10' 0'

	Spigot	**Hancor - 1**	Bell	Spigot	**Hancor - 2**	Bell	Spigot	**Hancor - 3**	Bell	Spigot	Bell
1)	48 1/4	48 1/8	48 3/4	48 1/2	48 1/2	48 1/2	48 1/4	48 1/8	48 1/4	48 1/4	48 7/8
2)	47 1/2	48 1/4	47 1/2	47 1/2	47 3/4	47 1/2	47 3/4	47 1/4	47 7/8	47 1/2	47 3/4
3)	45 3/4	47 3/4	47	47	47 3/4	47 1/2	47 1/4	47 3/4	47 1/2	47	47 3/4
4)	48 3/4	48 1/4	48	48	48 1/2	48 1/2	48	48 1/4	48 1/4	48 1/4	48 1/2

	Spigot	**ADS - 1**	Bell	Spigot	**ADS - 2**	Bell	Spigot	**ADS - 3**	Bell	Spigot	Bell
1)	47 7/8	47 3/8	47	47 1/4	47 3/4	47 1/4	47	47 3/4	47 3/4	47 7/8	47 7/8
2)	47	47 3/8	46 1/2	46 1/2	46 3/4	46 3/4	47	46 5/8	46 3/4	47	46 7/8
3)	45 1/2	46 1/2	46 1/2	46 1/8	45 3/4	46	46 1/2	46 1/4	45 3/4	46	45 5/8
4)	46 3/4	46 3/4	46 7/8	46 7/8	46 1/2	46 1/2	46 3/4	46 3/4	46 1/2	46 3/4	46 1/2

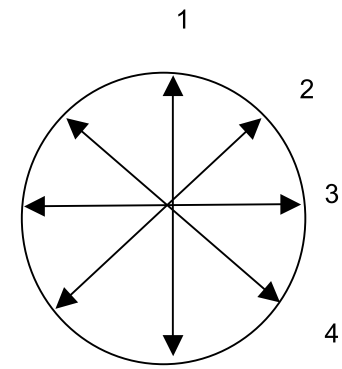
Notes:

A) All measurements facing West
B) All measurements in inches
C) 48" Hancor and ADS HDPE pipe with 3-4 feet of cover
D) Trench subcut to 1 1/2 feet below bottom of pipe
E) Backfill material - graded sand and compacted to 95% proctor density

Hancor Pipe Deformation Summary

Pipes were installed on September 1, 2000.
Sep. 8 measurements were thus 1 week after installation, while
Oct. 4 measurements were thus 1 month after installation.

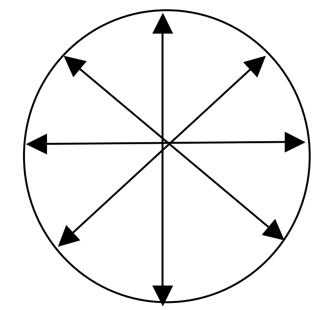
The Values in the table below represent the delta difference from the initial measurements taken immediately after installation.



West ← Flow ← Flow ← Flow ← Flow East

		70'	60'		50'	40'		30'	20'		10'	0'
		Spigot	**Hancor - 1**	Bell	Spigot	**Hancor - 2**	Bell	Spigot	**Hancor - 3**	Bell	Spigot	Bell
Sep. 8, 2000	1)	7/16	- 1/4	- 1/4	0	- 1/16	- 1/16	- 1/8	- 3/16	0	1/16	7/16
	2)	1/4	- 3/16	- 11/16	- 3/8	- 5/16	- 3/16	- 1/8	- 1/4	- 1/4	- 1/8	7/16
	3)	-1 1/16	- 1/16	- 5/8	- 5/16	0	- 3/16	- 1/8	- 1/16	- 3/8	- 1/8	- 9/16
	4)	1/4	- 5/16	1/8	3/16	- 1/8	0	1/16	0	- 5/16	3/16	- 5/8
Oct. 4, 2000	1)	1/16	- 3/4	- 1/8	- 1/8	0	- 1/16	- 1/4	- 9/16	- 1/4	1/16	5/8
	2)	- 1/8	- 1/2	- 3/4	- 3/8	- 5/16	- 1/4	- 1/8	-1 3/8	- 3/16	- 1/8	- 1/16
	3)	-2 3/16	0	- 5/8	- 1/4	- 1/4	- 1/8	- 1/8	- 3/16	- 3/4	- 1/2	- 15/16
	4)	3/8	0	- 1/4	- 1/16	1/8	- 1/8	- 1/16	0	- 13/16	- 1/4	- 1/8

ADS Pipe Deformation Summary



Pipes were installed on September 1, 2000.
Sep. 8 measurements were thus 1 week after installation, while
Oct. 4 measurements were thus 1 month after installation.

The Values in the table below represent the delta difference from the initial measurements taken immediately after installation.

West ← Flow ← Flow ← Flow ← Flow — East

70' 60' 50' 40' 30' 20' 10' 0'

		Spigot	ADS - 1	Bell	Spigot	ADS - 2	Bell	Spigot	ADS - 3	Bell	Spigot	Bell
Sep. 8, 2000	1)	5/8	- 1/8	0	1/16	0	- 1/8	- 3/16	0	0	1/16	5/8
	2)	0	- 1/8	- 1/4	- 5/16	0	1/16	0	- 1/16	3/16	1/8	1/8
	3)	- 15/16	- 1/16	- 1/4	- 1/4	- 1/8	- 1/16	0	- 1/8	1/8	1/16	- 13/16
	4)	- 1/16	7/8	3/16	1/8	- 1/4	0	- 1/8	- 1/8	- 3/8	- 1/4	- 3/8
Oct. 4, 2000	1)	7/8	- 1/4	- 3/8	1/8	0	1/16	- 1/8	0	- 1/8	0	1 1/8
	2)	- 1/4	3/8	- 1/2	- 7/16	- 1/8	- 1/16	- 1/8	- 3/16	1/4	1/8	1/8
	3)	-1 11/16	- 1/8	0	- 5/16	- 1/4	- 1/16	- 1/8	- 1/8	- 1/16	- 3/16	-1 7/16
	4)	0	- 3/8	1/8	1/8	0	- 1/8	- 1/8	- 1/8	- 3/8	- 5/16	- 3/8

Flowline Profile
October 4, 2000

CTH E, Polk County
2 Miles north of McKinley, WI.
Measurements by Robert Reukema (WisDOT) & Roger Baldwin (Hancor)

Vertical measurements (inches) from laser beam to pipe invert. Laser beam set on jig. Beam went down center of pipe.

Pipe	West End	Midpoint Pipe1	Joint 1/2	Midpoint Pipe 2	Joint 2/3	Midpoint Pipe 4	Joint 3/4	East End
Hancor	N/M	4 1/8	4 5/8	4 5/8	4 1/2	4 1/4	4 1/4	N/M
ADS	N/M	4 5/8	4 7/8 *	5 1/4 **	4 7/8	5 1/4	5	N/M

* - Invert of pipe at this point was installed approximately three inches north of the laser beam.
** - Invert of pipe at this point was installed approximately two inches north of laser beam.

N/M = Not measured

APPENDIX B

SUBGRADE STABILITY REQUIREMENTS
FOR LOCAL ROADS

INTRODUCTION

This is a condensation of the Illinois DOT's Subgrade Stability Manual and has been prepared to give the designer guidance on identifying and treating unsuitable subgrade material. The designer is required to use it for all Class I and II roadways. Its use is optional for all Class III and IV roadways.

Subgrade stability plays a critical role in the construction and performance of a pavement. A pavement's performance is directly related to the physical properties of the roadbed soils as well as the materials used in the pavement structure. Subgrade stability is a function of a soil's strength and its behavior under repeated loading. Both properties significantly influence pavement construction operations and the long-term performance of the subgrade. The subgrade should be sufficiently stable to:

1. Prevent excessive rutting and shoving during construction;

2. Provide good support for placement and compaction of pavement layers;

3. Limit pavement resilient (rebound) deflections to acceptable limits; and

4. Restrict the development of excessive permanent deformation accumulation (rutting) in the subgrade during the service life of the pavement.

While the effect of less satisfactory soils can be reduced by increasing the thickness of the pavement structure, it may be necessary to take other steps to ensure adequate support for the operation of construction equipment and placement and compaction of the pavement layers.

SUBGRADE STABILITY PROCEDURES

Many typical fine-grained Illinois soils do not develop a California Bearing Ration (CBR) in excess of 6 to 8 when compacted at, or wet of, optimum moisture content. (Note: The Department's Illinois Bearing Ration (IBR) is considered equal to CBR.) Thus the designer must use one of the three remedial procedures listed below when the insitu soil does not develop a CBR in excess of 6 to 8:

1. Undercut and backfill;
2. Soil-lime mixture; or
3. Moisture-density control.

NOTE: For pavement design purposes, the insitu CBR prior to the remedial subgrade treatment should be used.

Insitu CBR may be determined by use of a Corps of Engineers hand-held cone penetrometer, or a dynamic cone penetrometer (DCP). Correlations relating Corps of Engineers cone penetrometer and DCP test results to CBR values are summarized in Table 1. The Bureau of Local Roads and Streets can be contacted for additional help in determining a field CBR value.

TABLE 1

Subgrade Strength Relationships

CBR	Corps of Engineers Cone Index, psi[1]	DCP Penetration Rate, in./blow[2]
1	40	4.6
2	80	2.7
3	120	1.9
4	160	1.5
5	200	1.3
6	240	1.1
7	280	1.0
8	320	0.9
9	360	0.8

1. $\text{CBR} = \dfrac{\text{Cone Index, psi}}{40}$

2. LOG CBR = 0.84 - 1.26 LOG (Penetration Rate, in./blow)

I. Undercut and Backfill

Undercut and backfill involves removing the soft subgrade to a predetermined depth below the gradeline and replacing it with granular material. This option is appropriate for localized area base repairs as well as for new construction. The granular material helps distribute the load over the unstable subgrade and serves as a working platform for construction equipment. The required removal and backfill depth can be determined from Figure 1. The use of granular material with good shear strength is recommended. Factors that increase shear strength of a granular material are:

1. Using crushed materials;
2. Increasing top size;
3. Using well-graded materials (as opposed to one-size gradations);
4. Reducing PI of fines; and
5. Lowering fine content.

A geotextile may be used between the subgrade and the granular material to keep the subgrade layer separate from the granular layer, thus reducing the required granular thickness. The Bureau of Local Roads and Streets should be contacted for assistance in designing the appropriate granular thickness when geotextiles are used.

II. Soil-Lime Mixture

Unstable subgrades may be treated with a “soil-lime mixture” (LR 302) to improve subgrade stability for new construction or large reconstruction projects. The thickness requirements shown in Figure 1 for granular backfill may also be used to determine the thickness of the soil-lime mixture layer.

If a soil-lime mixture is to be used, it is necessary to perform laboratory tests to determine if the soil is “reactive” and to determine the percentage of lime necessary for the soil to develop a minimum CBR of 8 to 10. The designer commonly requires 0.5 percent more lime than the laboratory tests indicate to account for variables in the field.

If the CBR immediately upon completion of the soil-lime mixture is less than 8 to 10, the engineer has the option of allowing the soil-lime mixture to field cure in an attempt to obtain a CBR of 8 to 10. If a CBR of 8 to 10 is not attainable with a field cure, or if the engineer opts not to wait for a field cure, addition of a granular layer will be required. (Undercutting may be necessary prior to placing the granular layer in cases of grade restrictions.) The thickness of the granular layer and the soil-lime mixture layer can be combined to meet the required thickness shown in Figure 1. The minimum granular layer thickness should be 4 inches. The minimum soil-lime mixture layer should be 10 inches. (Thickness adjustments may be modified to fit field conditions.)

Alternative stabilizing agents such as cement, cement kiln dust, or fly ash may also improve subgrade stability. The effectiveness of these stabilizing agents should be evaluated by analysis of strength and stiffness modifications, curing requirements, thickness requirements, and permanency of treatment. Alternate stabilizing agents must be approved by the Bureau of Local Roads and Streets.

III. Moisture-Density Control

A Soil at or wet of its optimum moisture content may not provide adequate subgrade stability when compacted to 95 percent of the standard laboratory density, as required by current IDOT specifications. Moisture controls as well as density controls may be required to ensure the proper compaction necessary to obtain a stable subgrade. Quantitative values of permissible compaction moisture content can be added to the compaction specifications to accomplish this. Laboratory testing is required to determine appropriate compaction densities and moisture contents.

Draining the grade and drying the top portion of the subgrade by disking or tilling may control excess moisture at the time of construction, but it may be difficult to maintain that moisture condition throughout the pavement’s life. This method of remedial treatment is the least permanent of the three discussed.

TREATMENT GUIDELINES

The designer should use the following guidelines to determine which of the three remedial treatments is appropriate.

1. Specific details for each subgrade stability alternative should be determined. The required depth of undercut and backfill, the lime percentage and layer thickness required, and the moisture and density levels required to achieve the needed stability levels should be determined.
2. The alternate procedures should be compared by considering construction variabilities, economics, permanence of treatment, and pavement performance benefits.
3. The best option should be selected.

More detailed information regarding subgrade stability requirements for local agency pavement design are detailed in the Department's Subgrade Stability Manual. The designer is referred to this manual for additional information.

SUBGRADE STABILITY EXAMPLE

Determine the subgrade treatment alternatives for a soil having an insitu CBR of 4.

1. Based on Figure 1 and a CBR of 4, remedial procedures are required.
2. The three alternate treatments available are listed below along with specific requirements.
    a. Undercut and Backfill: From Figure 1, 11.5 inches of granular material are required.
    b. Soil-Lime Mixture: Figure 1 shows that 11.5 inches of soil-lime mixture would be required. If the immediate CBR of the soil-lime mixture obtained in the field is less than 8 to 10, the following options are available to the engineer:
        - Field-cure the soil-lime mixture until a CBR of 8 to 10 is achieved or;
        - Full- or partial-depth removal and replacement with granular material. In this case, 10 inches (minimum thickness) of soil-lime mixture and 4 inches (minimum thickness) of granular material would be suitable.
    c. Moisture-Density Control: Moisture and density specifications can be added to the contract documents to control compactive efforts, thus assisting in obtaining a stable subgrade. Laboratory testing can determine the appropriate compaction densities and moisture contents. Disking or tilling may be necessary to control excess moisture.

After comparing these three options, the best option should be selected and specified in the project plans. The designer should still use the insitu CBR for pavement design purposes rather than the CBR after the remedial treatment.

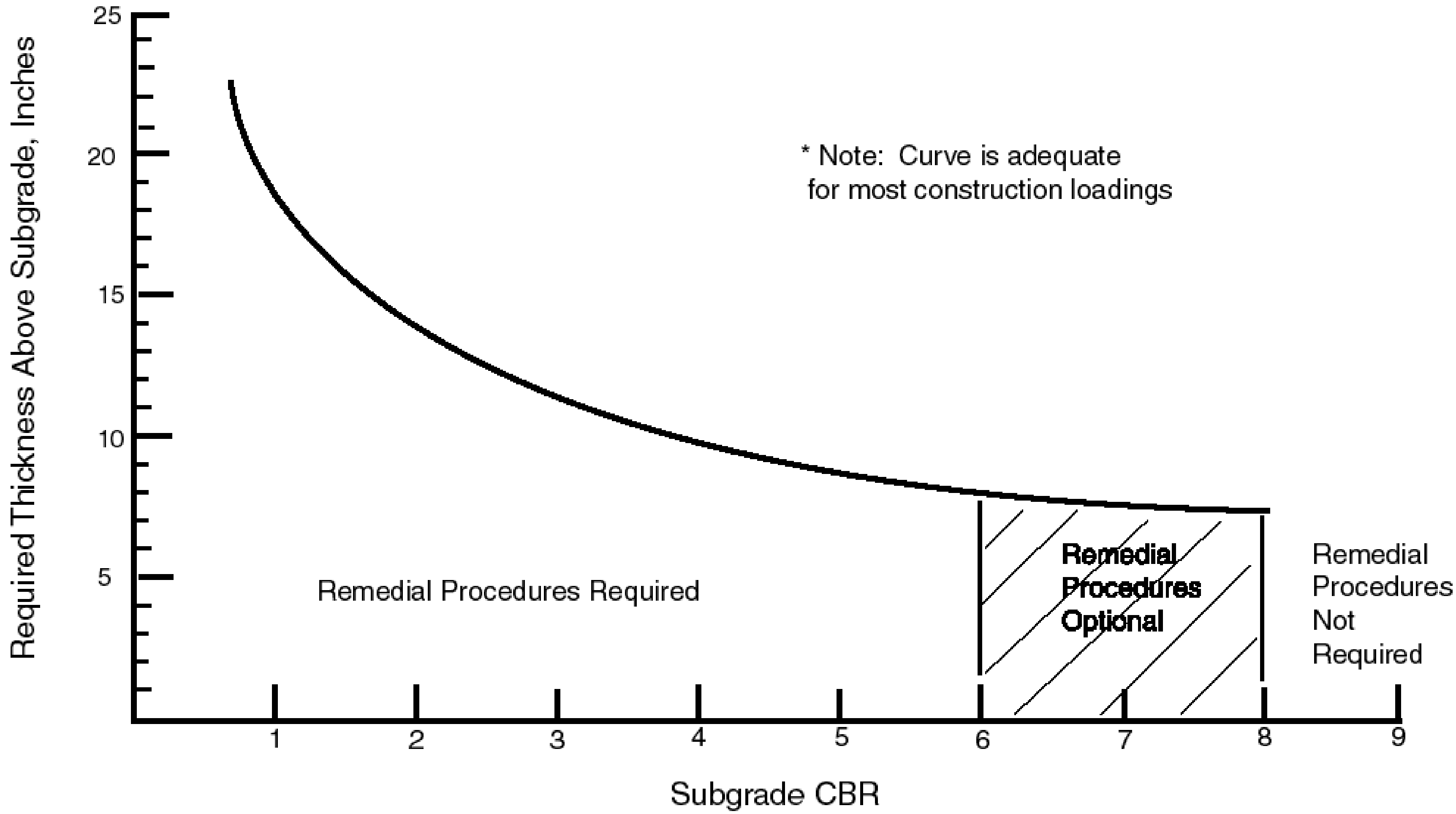


Figure 1: CBR-Based Thickness Design for Undercut and Backfill and Lime-Modified Soil Remedial Procedures

APPENDIX C

Print 1. View of the inlet of the old metal corrugated culvert pipe. Notice the deterioration of the pipe on the bottom due to the acidic water.

Print 2. Another view looking at the old pipe from the inlet end.

Print 3. View of the old pipe prior to removal.

Print 4. A closer view of the same image above.

Print 5. View of the old pipe being dug out looking from the outlet side.

Print 6. View of the old pipe looking from the inlet side.

Print 7. View of the outlet and scour hole of the old pipe. Most of the water was pumped out of the scour hole prior to the removal operation.

Print 8. View of the trench and preparation of the bedding material looking from the outlet end.

Print 9. Placing the ADS pipe on the bedding material, Hancor pipe is on the right. Notice the ADS pipe has a smooth exterior with no corrugation.

Print 10. Showing the backfilling and compaction of the first two pipe sections.

Print 11. The first two pipe sections after 4 compacted lifts.

Print 12. Another view of the pipes during the backfill and compaction operation.

Print 13. The final lifts are being spread and prepared.

Print 14. Vibratory steel wheeled roller compacting the final lifts.

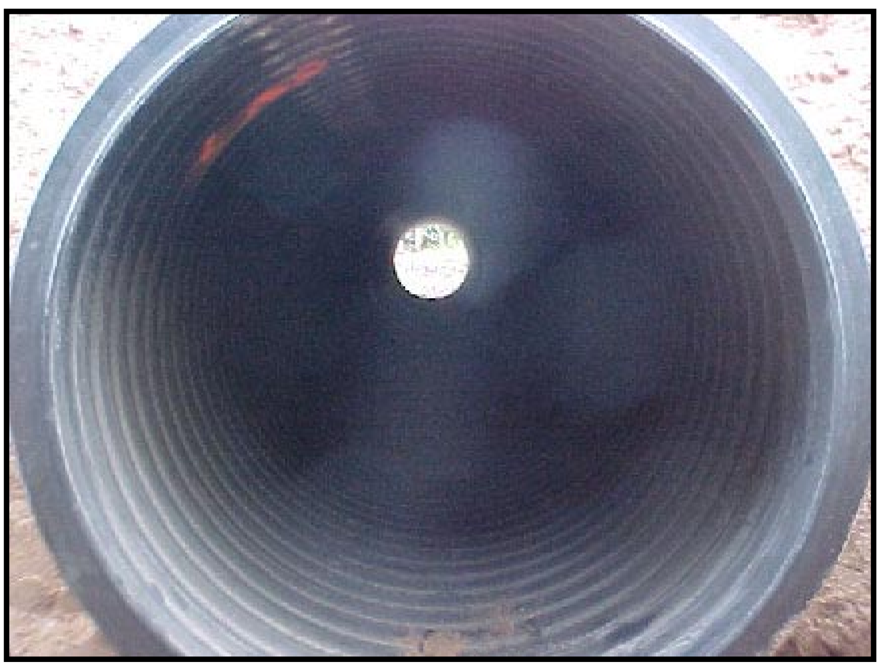
Print 15. The final lift being compacted.

Print 16. Placement of the end wall aprons, the bucket being used to “snug” up the apron.

Print 17. Another view of the end wall aprons. Notice the lip or groove on the Hancor pipe in the foreground providing sound attachment of the end wall apron to the culvert pipe.

Print 18. A close up view of the end wall apron attachment to the Hancor pipe.

Print 19. View of the ADS pipe after installation showing no noticeable deformation from the installation.



Print 20. View of the Hancor pipe after installation showing no noticeable deformation from the installation.